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ABSTRACT

This study attempted to produce a dynamic decision model for an ongoing learning situation presented via computer-assisted instruction (CAI). In addition to student performance on learning frames, criterion frames, and quiz items, the study was concerned with additional learning variables such as latencies for each of the above measures, and the subject's confidence of his response on the criterion of quiz questions. The relationship of these variables to quiz and final examination performance was investigated through correctional analysis. Based on the results of correlation and regression analyses with the quizzes and final exam as the dependent measures, the relevant variables were incorporated into the decision model. The decision model was implemented and validated with an independent group of students. It was shown to be effective in identifying those trainees who needed remedial instruction. A reference list, samples of material used to gather data, and equations developed to analyze data are appended. (Author/JY)

CAI CENTER

TECH REPORT

DEVELOPMENT OF A MODEL FOR ADAPTIVE TRAINING VIA COMPUTER-ASSISTED INSTRUCTION UTILIZING REGRESSION ANALYSIS TECHNIQUES

Walter Dick, LeRoy Rivers, Arthur D. King,
and Duncan N. Hansen

Technical Report No. 10
June 30, 1970

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SECTION I

INTRODUCTION

A major technological advance has occurred in recent years and can be described as "computer technology." Many investigators (Dick, 1965; Hansen, 1966; Gentile, 1967; Zinn, 1967) report that one of the major advantages of using a computer for training stems from its capability to adapt the instruction based on the individual's most recent performance as well as his past history. Therefore, it can be hypothesized that a computer, because of its unique monitoring capability, would be an ideal manager of an adaptive training system. "Adaptive" is used throughout this report to refer to a process or technique for improving performance by modifying the instructional program to meet the individual characteristics of the trainee. Adaptive then is synonomous with individualization rather than adaptive in the constant error sense.

There have been several investigations concerned with developing a methodology for designing and implementing adaptive training systems. One quantitative approach to developing an adaptive training system has utilized the techniques developed within mathematical learning theory. The investigators attempted to utilize formal mathematical models of the learning process as a basis for the design of adaptive training systems (Deer & Atkinson, 1962; Atkinson & Hansen, 1966; Groen & Atkinson, 1966; Karush & Deer, 1966). Deer and others (1965) concluded that "the improvement of teaching procedures by seeking an optimal way of presenting the stimulus materials may have important practical consequences only in specific situations, for example, where there is a considerable degree of interdependent relations among the stimulus materials." Another quantitative approach can be identified in the research efforts of Smallwood, Weinstein, and Eckles (1967). These investigators proposed the use of response probability estimation models to optimize the instructional strategy. Under the probability estimation model, the particular instructional block that a trainee receives is based on decision rules that are dynamic in the sense that the trainee's accumulating performance history affects the decision process. Thus far, progress has been difficult in using quantitative methods for adapting instruction to the individual differences of the learners.

A second major technique for designing adaptive systems (Cronbach, 1967) is to adapt the instruction to various facets of the trainee's aptitudes or traits. However, as Cronbach & Snow (1969) have reported, research in the area of aptitude-treatment interaction has produced inconsistent findings. In addition, adapting instruction on the basis of pre-conditions does not permit the flexibility to change the instructional program during the acquisition of the material.

A third major approach in designing adaptive training systems has involved the use of empirical techniques. Data on within-course variables generated by an initial group of trainees is utilized in establishing the branching or adaptation points in the instructional program, as well as the decision criteria to be employed at each point. As subsequent trainees proceed through the instructional materials, data is collected on the relevant variables and the trainees are branched to specific content based on their individually generated within-course performance. The use of this technique can be seen in the efforts of Silberman and others (1961). Using a short course on logic, Silberman et al. established branching procedures based on cumulative errors within a topic, but found no significant differences on criterion performance when compared with a fixed sequence. The investigators reported that "it may be conjectured that some measures such as response latency or subject's self-evaluation are more appropriate than error rate and that the computer should have considered these behavior measures for its branching decisions instead of, or in addition to, errors." Coulson and others (1962) used the logic materials as did Silberman, but their branching decisions were based on both the cumulative errors and the subject's evaluation of his own readiness to advance to new topics. Coulson et al. found a significant difference on criterion scores for the adaptive branching group when compared with a linear sequence group.

Using empirically developed branching rules, Melaragno (1966) compared the effectiveness of three adaptation procedures. The first used previous students' performances on the training materials as the basis for branching decisions. The second procedure was based on previous students' pre-training abilities, a prediction condition, and the third treatment, the linear sequence condition served as a control group. Multivariate analysis of posttest scores and training times indicated that the branching condition was superior to the linear condition, but no significant difference was found between the branching and prediction condition.

The goal of an adaptive training system is to optimize performance and/or time by adapting the instruction on the basis of each individual's performance. Given the unique monitoring capabilities of the computer, a viable approach would be to develop a decision model to be used in the logic of the instructional program to take into account the trainee's performance within the instruction and to branch him to specific content based on that performance, in essence, an empirical approach. The question then arises as to the methodology that should be employed in developing such a decision model. It is to this question that the statement of the problem is addressed.

SECTION II

STATEMENT OF THE PROBLEM

The basic objective of this investigation was to develop a methodology for providing adaptive training via computer-assisted instruction. An effective utilization of the capabilities of the computer would involve the development of a dynamic decision model for adapting training. The implications for the development of a dynamic adaptive decision model would be the use of performance data collected during the actual presentation of the instructional materials to modify the trainee's performance within the course of training as well as future trainees.

The development of the adaptive decision model thus involves the identification of variables to be monitored during learning and the establishment of decision criteria for applying these variables to modify the behavior towards the training objectives. The use of regression analysis techniques would be an appropriate basis for building the adaptive model because variables that are effective predictors of final performance would be identified, and the relative weighting factors produced could be used in the decision process. This empirical approach for regression techniques utilizing within-course performance data involves a two-step process. An initial group of trainees would proceed through the training materials. Their data would be analyzed by regression analysis, and on the basis of this analysis, the adaptive decision model would be developed. Although linear regression has been extensively used in the analysis of data, it has yet to be utilized in developing dynamic decision models for adaptive training. The rationale for this empirical approach is that the performance data collected from the trainees during the actual training activity would more clearly reflect both the types of variables to be used and the types of decisions that are required to develop an effective adaptive training system.

The initial problem involved the identification of potential predictor variables that could be measured during learning, and that would enhance the effectiveness of the decision model. Certainly the most obvious learning variable which could be measured was the probability of correct responding. It was hypothesized that the greater the frequency of correct responding, the greater the probability that the trainees would also perform successfully on the final examination. A second variable identified for inclusion in the decision model was response latency. Latency is defined as the interval between the presentation of an information-question unit to a trainee and his response to that unit. It was hypothesized that since latency reflects varying degrees of facility with the instructional materials, the inclusion of this variable should add to the predictive capability of the model. A third variable, a performance related variable, considered for inclusion in the adaptive model was subjective confidence. Previous research by Shuford and Massengill (1966) and others has indicated that additional information can be gained from subjective confidence measures which is not available from conventional right-wrong scoring of test information. Numerous suggestions appear in the writing of Shuford and Massengill that confidence ratings can be used not only in testing situations but in an ongoing learning environment. Therefore, it can be hypothesized that the utilization of subjective confidence, i.e., an indication by the trainee of his confidence in his progress with the learning materials, might increase the effectiveness of the adaptive decision model.

The second major problem area concerns the determination of the unit of analysis. That is, would the most effective adaptation be obtained by analyzing the learning data over a series of frames covering a specific concept, or should the data be analyzed over a series of related concepts covering a larger number of frames? The establishment of the unit of analysis determines the point at which adaptation can be effected. The unit of analysis should be large enough to provide a stable indication of behavior but be responsive enough to provide for adaptation while the learning is still proceeding.

In summary, this investigation attempted to answer the question of whether regression analysis techniques can be used to identify the within-course variables that related to final performance, and whether the decision logic can be built from these techniques to provide dynamic adaptive training via computer-assisted instruction.

SECTION III

METHOD

A. INSTRUCTIONAL MATERIALS

The materials which were used in this study were a portion of a Boolean algebra course which had been previously developed for the Naval Training Device Center under Contract No. 68-C-0071. These materials were specifically selected since the target population for the development and verification for the adaptive decision model was a group of Naval Reserve officers and enlisted men.

The content of the Boolean algebra course which was selected for the study included two major sections: introduction to Boolean algebra, and three Boolean algebras (mathematical logic, set theory, and switching networks). (Appendix A contains a list of the eight concepts comprising these two sections.) A task analysis of the concepts in the Boolean algebra course indicated that they form what appears to be a sequential hierarchy of interrelated skills which the student must learn.

The original design of these instructional materials was quite similar to Crowder's (1959) limited branching instructional strategy which has been employed in the field of programmed instruction. That is, information frames and question frames were utilized. The question frames had multiple choice formats with four alternatives which required specific responses from a trainee. If the trainee responded incorrectly, he was told that he was incorrect, and at times was given assistance, i.e., cues for identifying the correct answer.

For the purposes of the present study, the instructional materials were divided into two forty-minute instructional units. As shown in Appendix A, Unit I included three concepts and Unit II covered five concepts. For each concept a "preview frame" was written. This was a frame which was, in fact, a question which attempted to measure whether a trainee had already learned the concept which was to be taught next. A preview frame preceded the presentation of each concept and was clearly labeled as a pretest question. Similarly, criterion questions were developed for each concept. These criterion questions closely paralleled the intent of preview questions in that both were designed to measure the achievement on the concept. There was a series of information and question frames between the preview and criterion frames for each concept. This segment of the training materials will be referred to as the acquisition stage--where the learning of the concept is acquired. The number of information and question frames within each concept is presented in Appendix A.

A frame is operationally defined as that amount of material that could be displayed on the cathode ray tube screen at one time which required an answer or continue response from the trainee. Two other questions were also developed which were parallel to the preview and criterion frames. These questions were used in an end-of-unit quiz and in a final examination on all of the instructional materials. Therefore, for each concept taught, there were four parallel test questions developed. These questions were used for the following purposes: (1) as a preview or pretest measure which was administered just prior to instruction on a concept, (2) as a criterion measure which tested for acquisition of a concept immediately after it had been taught, (3) as an end-of-unit question which was utilized to test those concepts which had been taught during that session, and (4) as a final examination question which was administered at the conclusion of the entire learning sequence. The learning sequence for the trainees is shown in figure 1.

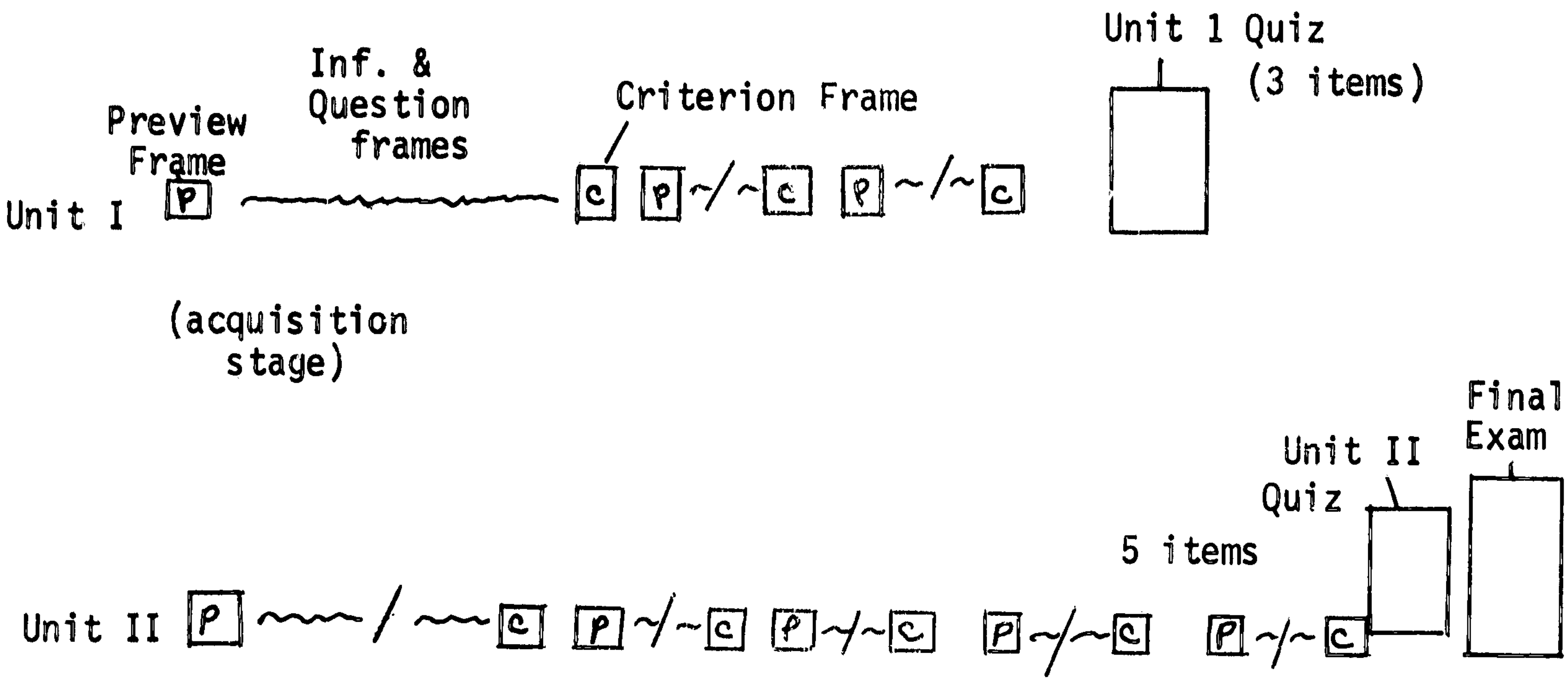


Figure 1.--Trainee Learning Sequence

B. EQUIPMENT

The instructional materials were presented by means of the IBM 1500 system located at the Florida State University Computer-Assisted Instruction Center. Each instructional terminal consists of a CRT (television screen) display as output, and both keyboard and light-pen response modes as trainee input devices. The trainee's performance and latency for each response were recorded automatically by the computer.

C. EXPERIMENTAL DESIGN

There were essentially four steps in the execution of the total experimental design. After the learning materials had been completely coded and prepared for use by the trainees, a test group of public high school students was involved in a pilot study in order to check that the instructional program was running effectively and to determine that all the learning parameters were being measured and recorded correctly. Following this pilot study, a group of Naval Reservists studied the Boolean algebra CAI program in its initial form in order to collect the learning data which would be utilized to build the adaptive decision model. The third step was to use the data from the first group of Naval Reservists for developing the adaptive decision model and to insert the appropriate remedial instruction into each of the learning units. The final step involved having a second group of Naval Reservists proceed through the Boolean algebra program to which had been added (1) the coding in the program logic to monitor the appropriate within-course variables, (2) the decision models which would detect those trainees who would need additional instruction, and (3) the remedial loops which would optimize their final performance. The initial group of Naval Reservists will be referred to as the Phase 1 trainees and the second group of Naval Reservists, the validation group, will be referred to as the Phase 2 trainees.

D. MEASUREMENT TECHNIQUES AND MODEL BUILDING

The three basic variables which were used in developing the adaptive decision model were acquisition performance, latency, and subjective confidence. These three measures were recorded several times during the presentation of each individual concept. Performance, latency, and confidence were recorded for each preview question, each criterion question, and each quiz question. The percentage correct and the latency during the acquisition stage (frames that were presented between the preview and criterion questions) were also recorded.

This collection of independent measures was used as the input for the multiple regression analyses. The multiple regression technique was selected as the basis for building an adaptive model because:

1) it identifies those variables which account for a significant amount of the performance, and thus can be used in the adaptive decision model, and

2) it produces weighting factors which can be applied to the performance data to predict future performance.

Given the input of variables mentioned above, the problem remained to determine the unit of analysis to be utilized in building the instructional model. Previous studies, in which remedial branching techniques were applied on the basis of the response to a single learning frame, have had limited success. It was hypothesized that a larger unit or sample of behavior was needed in order to provide a stable indication of the trainee's performance. The largest sample of behavior would be performance across the total course. In this case, adaptation would take place only after the basic core of training was completed. Since the material did seem hierarchical in nature, the most appropriate unit of analysis would be somewhere between a single frame and the total course. It was felt that the unit of analysis should provide a stable indication of behavior but be responsive enough to provide for adaptation while the learning was still proceeding. Therefore, the decision was made to develop the adaptive decision models and intervene with remedial instruction at four locations within the instructional sequence. Remedial instruction was located just following instruction on the final concept for each unit, i.e., following all of the instructional activities for each unit but preceding the end-of-unit quizzes. Remedial instruction also followed the end-of-unit quizzes. Figure 2 displays the points of remediation.

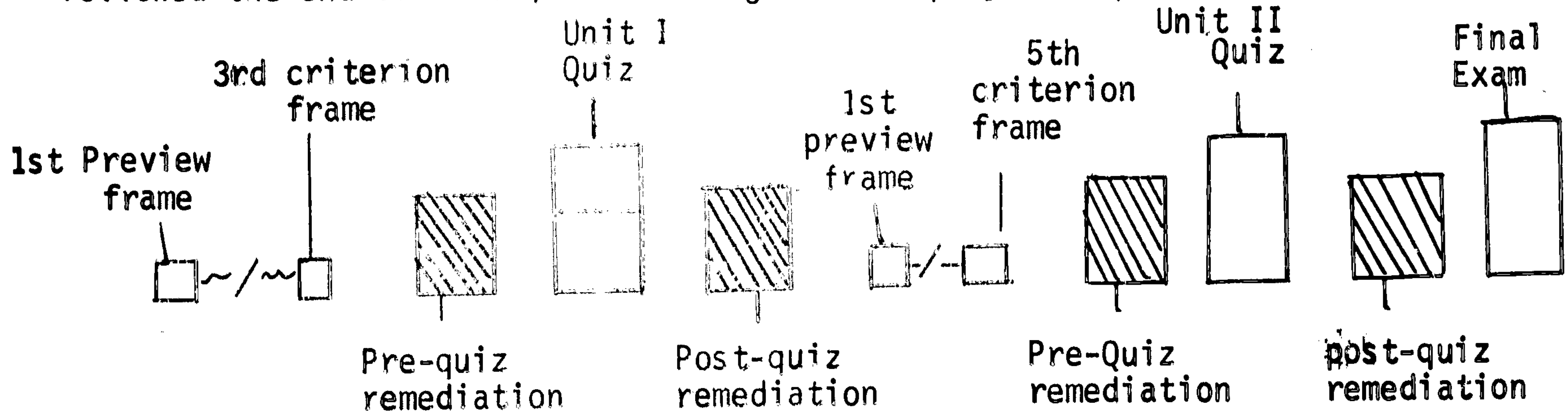


Figure 2.--Points of Remediation

The dependent variable used as the criterion for the intervention decision prior to the quiz was the predicted unit quiz performance. The dependent variable for the intervention decision following the end-of-unit quiz was the predicted performance on the final examination for the concepts involved within the particular unit. In essence, data was accumulated over several concepts in order to determine if remedial activities would be required, both following the learning sequence for a unit, and following quiz activities for a unit. In order to reach these decisions, data from the following variables was available for inclusion in the multiple regression equations at the end of the learning sequence: performance, latency and confidence ratings on both preview and criterion questions; and performance (percent correct) and latency during the acquisition stage. This data served as input to predict the performance of the Phase 2 trainees on the end-of-unit tests. Similarly, after the unit quiz, cumulative data on performance, latency, and confidence on the quiz served as input to predict performance on the corresponding final examination questions.

The decision rule for providing remedial instruction for the Phase 2 trainees prior to and following the quiz for each unit was that a Phase 2 trainee's predicted performance on the quiz or final examination had to be equal to or greater than the mean performance on these tests by the Phase 1 trainees, whose learning data was utilized in building the optimization model. For example, if a Phase 2 trainee's predicted quiz performance was less than the mean quiz performance achieved by the initial group of Naval Reservists, then that trainee was branched to the pre or post quiz remedial instruction for the unit.

E. PROCEDURE

1. PHASE 1 STUDY

The subjects were eleven Naval Reservists from the Naval Training Reserve Center in Tallahassee. The subjects were drawn from a population of enlisted men, and two of the subjects indicated that they were familiar with simple Venn diagrams.

The learning sequence for each trainee was essentially as follows: after a brief introduction to the CAI system and the instructional terminal, he was given instruction via the IBM 1500 system on the use of the confidence scale. This was followed by a preview question on the first concept which was to be taught. He was then asked to indicate his confidence in his performance on that question. The confidence scale is presented in Appendix B. Regardless of his performance, either right or wrong, he continued into the acquisition stage materials for that concept. The sequence was basically linear. At the conclusion of the instruction on that concept he was given a criterion or posttest question. He was also asked to indicate his confidence in his performance for that question. He then encountered the preview frame for the next concept.

This sequence continued over three concepts. After he indicated his confidence for the criterion question on the final concept for the unit, the end-of-unit quiz was administered via the terminal. The test consisted of one question for each of the concepts encountered during that instructional session. The trainees were allowed to take a short break before proceeding on to Unit II which contained five concept sequences. After the second unit, all students were given a paper and pencil final examination consisting of one test item for each concept of the eight concepts which had been taught in the entire learning program. After the final examination, the subjects were given an attitude questionnaire assessing their opinions about CAI presentation of the Boolean materials. A copy of this questionnaire is given in Appendix C.

The data acquired in Phase 1 was utilized to build the decision models which were used in the Phase 2 study.

2. PHASE 2 STUDY

The subjects were eleven Naval Reservists drawn from the same population of enlisted men from which the Phase 1 subjects were obtained. The instructions and procedures used here were identical to those used in Phase 1. For this group, however, the adaptive instructional model had been coded into the course logic via the programming language. At the selected locations, the subjects could receive remedial instructions based upon the outcome of the regression equation calculations which were dependent upon the trainee's performance during the instructional program. After completion of the instruction, these subjects were queried about their opinion of the effectiveness of the remedial instruction they received. The questions concerning the remedial instruction are given in Appendix D.

SECTION IV

RESULTS

A. PHASE 1

The following measures were obtained on the preview questions, criterion questions and quiz questions: performance, latency, and confidence ratings. The percent correct and the latency during the acquisition stage were recorded for each instructional unit. The final measure was the score on the final examination. The data on each of the twelve variables was summed across the three concepts in Unit 1 and across the five concepts in Unit 2. The means and standard deviations for these resultant twelve variables are given in Table 1. Tables 2 and 3 contain the intercorrelations of the variables.

TABLE 1

PHASE 1 - MEANS AND STANDARD DEVIATIONS

	UNIT 1		UNIT 2	
	Means	S.D.	Means	S.D.
Preview Performance[1]	1.82	1.09	3.64	1.20
Preview Latency[2]	62.28	25.26	216.63	65.19
Preview Confidence[3]	9.09	2.95	21.73	3.80
Criterion Performance	2.45	1.11	3.64	1.28
Criterion Latency	32.47	8.44	104.84	36.04
Criterion Confidence	13.00	3.16	22.64	4.52
Acquisition Performance	77.27	16.18	81.64	14.93
Acquisition Latency	773.32	163.62	1298.28	265.75
Quiz Performance	2.09	1.13	2.27	1.36
Quiz Latency	39.23	11.03	267.21	173.72
Quiz Confidence	12.82	2.56	21.09	4.39
Final Exam	2.36	1.13	2.64	1.36

[1]performance = number of correct responses. For Unit 1, the maximum possible is three; for Unit 2 the maximum possible is five. This also applies to criterion performance, quiz performance, and final exam.

[2]All latencies are given in seconds.

[3]based on a five point scale (1 = low, 5 = high confidence), the maximum possible for Unit 1 is 15; for Unit 2 the maximum possible is 25. This also applies to criterion and quiz confidence.

TABLE 2

PHASE 1 - UNIT 1

INTERCORRELATIONS*

		1	2	3	4	5	6	7	8	9	10	11	12
Preview Performance	1												
Preview Latency 2	2												
Preview Confidence 3	3												
Criterion Performance	4												
Criterion Latency	5												
Criterion Confidence	6												
Acquisition Perform.	7												
Acquisition Latency	8		.639										
Quiz Performance	9		.610										
Quiz Latency	10									.688			
Quiz Confidence	11		.633				.852						
Final Exam	12												

*Correlations above .735 are significant at $p < .01$; for all others $p < .05$

TABLE 3

PHASE 2 - UNIT 2

INTERCORRELATIONS*

		1	2	3	4	5	6	7	8	9	10	11	12
Preview Performance	1												
Preview Latency	2												
Preview Confidence	3												
Criterion Performance	4												
Criterion Latency	5												
Criterion Confidence	6		.670	.791	.869								
Acquisition Perform.	7		.622	.799	.763		.937						
Acquisition Latency	8		.660	.616	.610	.784							
Quiz Performance	9		.605										
Quiz Latency	10												
Quiz Confidence	11			.715	.892		.802	.629					
Final Exam	12									.564			

*Correlations above .735 are significant at $p < .01$; for all others $p < .05$.

14

1. DEVELOPMENT OF THE ADAPTIVE DECISION MODEL

The analysis of the Phase 1 data indicated unstable relationships between the preview performance, latency and confidence with the remaining variables. Therefore, in building the decision model, these three variables were not considered. Since intervention for remedial instruction could occur before each of the unit quizzes and/or after each of the unit quizzes, four separate stepwise regression analyses were conducted. The following five measures were initially entered to predict the unit quiz performance: performance, latency, and confidence on the criterion questions; percent performance, and latency during the acquisition stage. These five dependent measures were regressed on quiz performance. However, in developing the decision models for applying remedial instruction after the quiz, quiz performance, quiz latency, and quiz confidence were regressed on final examination performance for the corresponding units. The predictor variables accounting for a major portion of the variance as indicated by the multiple R for each of the four regression analyses are given in Table 4.

TABLE 4

VARIABLES USED IN THE REGRESSION EQUATIONS AND THE MULTIPLE R AND R^2 FOR THE EQUATIONS BY UNIT

	Pre-Quiz	Post Quiz
Unit 1	Acquisition Performance Acquisition Latency $R = .6068$ $R^2 = .3682$	Quiz Performance Quiz Confidence $R = .6506$ $R^2 = .4233$
Unit 2	Acquisition Performance Acquisition Latency Criterion Latency $R = .7674$ $R^2 = .5889$	Quiz Performance $R = .5637$ $R^2 = .3178$

The multiple R squared (R^2) shown in Table 4 indicated the amount of variance of the dependent variable (quiz and final examination performance) accounted for or predicted by the combination of variables in each of the four equations. The stepwise regression equations with the amount of variance accounted for with the addition of each variable for each of the four analyses along with the significance levels of the final equations are given in Appendix E. If the regression equations are to be effective, then the dependent variables (performance on the unit quiz, and performance on the final examination) should be reliable measures. The internal consistency reliability estimates of the quiz and final examination for each of the two units are given in Table 5.

TABLE 5

PHASE 1 QUIZ AND FINAL EXAMINATION RELIABILITIES BY UNIT

	Unit 1	Unit 2
QUIZ	.387	.484
FINAL EXAM	.543	.539

2. COURSEWRITER II IMPLEMENTATION

The variables used in the regression equation for predicting quiz performance on Unit 1 (as shown in Table 4) were acquisition performance and acquisition latency across the three concepts. The recoding of the Coursewriter programming statements involved summing these two measures across the three concepts in Unit 1, and coding in the regression equation calculations immediately after the last criterion question in that unit. These modifications permitted a prediction of how a trainee would perform on the quiz prior to his taking the quiz. If his predicted performance was equal to or greater than the mean performance on the quiz for Unit 1 based on Phase 1 data, then the trainee would be branched immediately to the quiz. If his performance was less than the mean performance when compared to the Phase 1 group, he would receive the remedial instruction. Prior to receiving the remedial instruction, a trainee's latency and percent performance within Unit 1 was compared with the means on the comparable variables obtained from the Phase 1 study. The trainee received the appropriate instruction indicating whether his performance was too low, whether he was taking too much time, or both. After this he was given the remedial instruction.

The relevant variables in the regression equation for predicting final examination performance on the first three concepts in Unit 1 were quiz performance and quiz confidence. The recoding of the Coursewriter II statements involved summing the quiz performance and quiz confidence across the three quiz questions from Unit 1. The regression equation calculations were coded into the computer logic so that the equations were calculated immediately after the last quiz question. For each trainee then, a prediction of his final examination performance on Unit 1 was obtained before he took the final examination. If his predicted final examination performance was less than the mean final examination performance on Unit 1 from the Phase 1 group, he was given remedial instruction. Prior to receiving the Unit 1 post quiz remedial instruction, the trainee received special instructions informing him why he was receiving the review. The same process was followed for Unit 2 using the variables as indicated in table 4.

3. DEVELOPMENT OF THE REMEDIAL MATERIALS

An item analysis of the criterion, quiz, and final examination questions was conducted for the pilot study trainees and the Phase 1 trainees. Analysis of these questions indicated certain learning problems within each concept. The remedial materials were specifically developed to alleviate these problems. The remedial materials which were inserted consisted of a review of each concept presented followed by one or two questions. Each of the questions was response sensitive in that each time a wrong alternative was selected, special feedback was given which indicated why it was wrong and a hint as to why the misconception might have arisen. The Unit 1 pre-quiz remediation contained three information frames and three response sensitive question frames. A parallel set of remedial materials was developed for the Unit 1 post-quiz adaptation. Unit 2 remediation consisted of two parallel sets of five information frames and six response sensitive question frames.

B. PHASE 2: THE VALIDATION STUDY

The variables used in the analysis of the Phase 2 Naval Reservists data were the same 12 variables identified in the Phase 1 study. The means and standard deviations per concept of these 12 variables for each of the 2 units are given in Table 6. Table 7 shows the number of times remedial instruction occurred for each trainee, and the amount of time, in seconds, that he spent on this instruction. A coding error kept all trainees from receiving the Unit 2 post-quiz remedial instruction. A post hoc analysis of the regression equation calculations indicated that 6 of the 11 trainees should have received remedial instruction.

The mean latency during acquisition for the seven trainees who received remedial instruction in Unit 1 was 951.1 seconds. The mean time taken to examine and respond to the remedial instruction was 229.2. The additional time required for remedial instruction represents a 24 percent increase in time to complete the Unit. For Unit 2, the mean latency during acquisition for the nine trainees who received remedial instruction was 1934.2 seconds. The mean time taken by these nine trainees on the remedial instruction was 229.2 seconds. The additional time required for remedial instruction in Unit 2 represents a 22 percent increase in time.

TABLE 6

PHASE 2 - PERFORMANCE, LATENCY, AND CONFIDENCE:
MEANS AND STANDARD DEVIATIONS

	UNIT 1		UNIT 2	
	Means	S.D.	Means	S.D.
Preview Performance[1]	1.09	.90	3.36	.87
Preview Latency[2]	56.77	25.34	223.98	50.04
Preview Confidence[3]	8.82	2.75	20.00	4.90
Criterion Performance	1.55	.79	4.00	.81
Criterion Latency	47.53	25.57	97.95	23.36
Criterion Confidence	11.91	2.55	21.64	5.22
Acquisition Performance	71.82	21.83	73.73	11.83
Acquisition Latency	812.05	181.19	1502.84	403.32
Quiz Performance	2.00	1.00	1.73	1.35
Quiz Latency	46.15	17.91	259.54	149.23
Quiz Confidence	11.82	2.64	18.45	4.80
Final Exam	2.18	.75	2.45	1.04

[1]performance = number of correct responses. For Unit 1, the maximim possible is three; for Unit 2 the maximum possible is five. This also applies to criterion performance, quiz performance, and final exam.

[2]All latencies are given in seconds.

[3]based on a five point scale (1 = low, 5 = high confidence), the maximum possible for Unit 1 is 15; for Unit 2 the maximum possible is 25. This also applies to criterion and quiz confidence.

TABLE 7

TRAINEES RECEIVING REMEDIAL INSTRUCTION
AND THEIR MEAN LATENCY BY UNIT

TRAINEE	UNIT 1 Pre-Quiz	UNIT 1 Post Quiz	Total Unit 1	UNIT 2 Pre Quiz	UNIT 2 Post Quiz	Total Unit 2
1		R**	17.8	R	*	54.8
2		R	53.6			
3						
4	R		72.5	R	*	75.4
5				R	*	91.2
6		R	65.0	R	*	88.2
7				R		27.3
8		R	89.7	R		106.1
9	R		65.2	R	*	63.8
10	R	R	170.7	R	*	41.6
11				R		223.1
SUM			534.5			771.5
MEAN			76.4			85.7

*These trainees should have received the remedial instruction, but did not due to a coding error in the computer programming language.

** "R" indicates that the trainee received remedial instruction.

C. COMPARATIVE ANALYSIS OF PHASE 1 AND PHASE 2

It was felt that due to a series of methodological problems and the small number of subjects, it would be inappropriate to conduct a series of sophisticated statistical analyses in comparing the control and experimental groups. It is often the case that such analyses lend undue authenticity to findings that should not be taken as conclusive, consequently limitations of the studies are not given proper consideration. It should be pointed out that this particular approach to adaptive training was an initial developmental effort. Therefore, the comparative results are presented for descriptive purposes only. The data for the following graphs are taken from tables 1 and 6. Overall, the training material used in this study was an introduction to Boolean algebra. The data from each unit are presented separately since the two units differed in basic content as well as degree of difficulty.

1. PERFORMANCE

Figures 3 and 4 present the mean number correct on the preview, criterion, quiz and final examination questions for Unit I and Unit II respectively. In making comparisons between Unit I and Unit II it should be remembered that Unit I reflects performance on three concepts whereas Unit II reflects performance on five concepts. It should also be noted that the preview and criterion questions were spaced throughout the instruction for each unit, the quiz questions were presented in a block at the end of each unit, and the final examination questions were presented after all instruction was completed.

The points of adaptation in terms of remedial instruction took place before and after the quiz for each unit. Therefore, the major comparisons of interest are performance on the quiz and final examination questions. Figure 3 shows that the adaptive model group (Phase 1) started with less prior knowledge and gained slightly less in comparison with the linear training group as indicated by performance from preview to criterion. However, the performance of the adaptive model group (Phase 2) on the Unit I quiz and final examination questions was comparable to that of the control group (Phase 1). In addition, the control group shows a drop in performance from the criterion to the quiz whereas the adaptive model group shows a gain.

Figure 4 indicates that the apparent difference in prior knowledge of the two groups shown in figure 3 is no longer noticeable in Unit II. The increased proficiency of the adaptive model group (Phase 2) in Unit I was maintained in Unit II. Figure 4 also indicates that the performance on all measures in Unit II for the two groups was quite parallel. The drop in performance from the criterion to the quiz and final examination questions indicates that either the training materials in Unit II were poorly designed or that the quiz and final examination were much more difficult than the criterion questions. Apparently the remedial training presented in this unit was not sufficient to overcome either case.

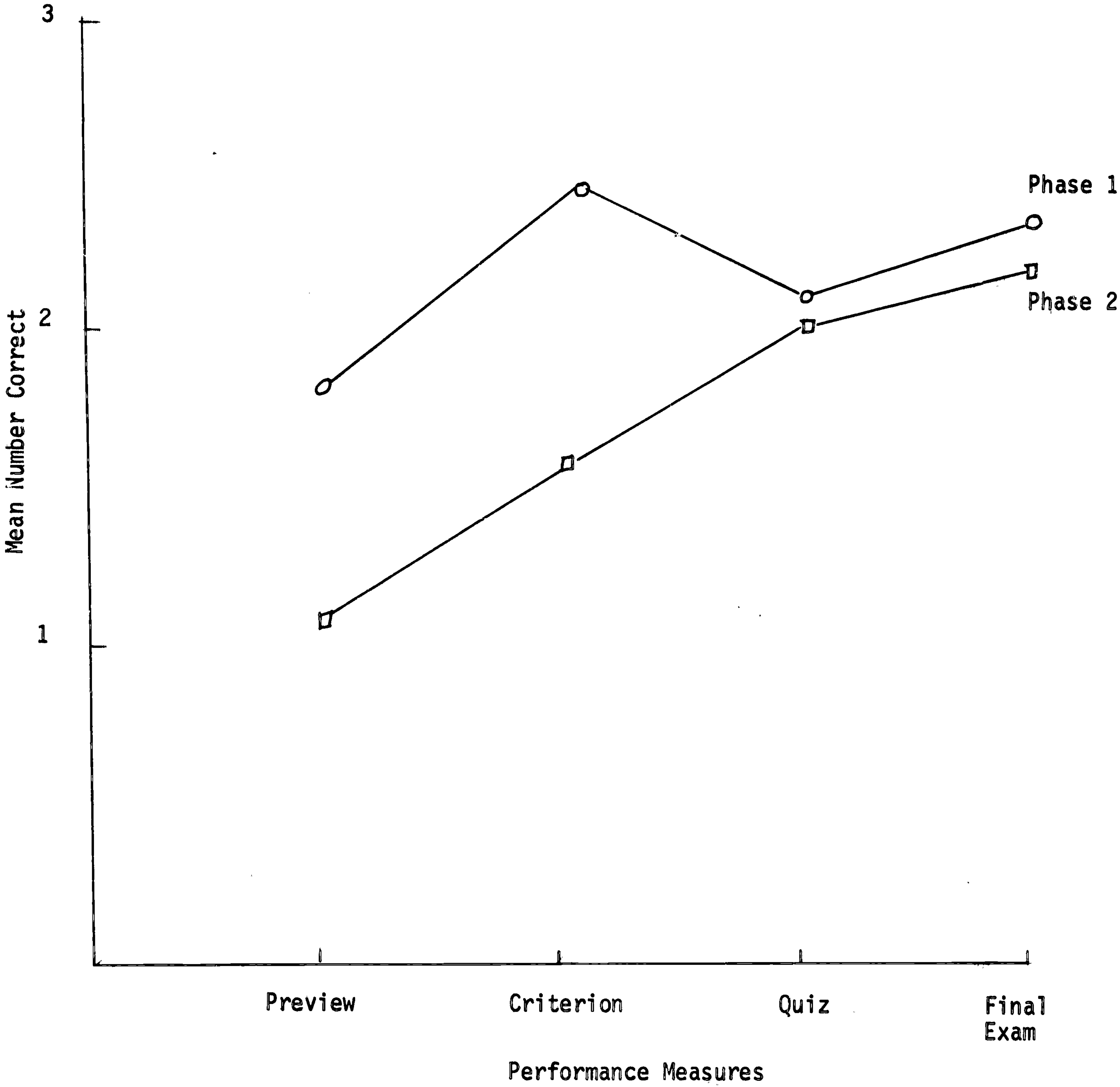


Figure--Mean Number Correct on Unit 1 Preview, Criterion, Quiz and Final Examination Questions

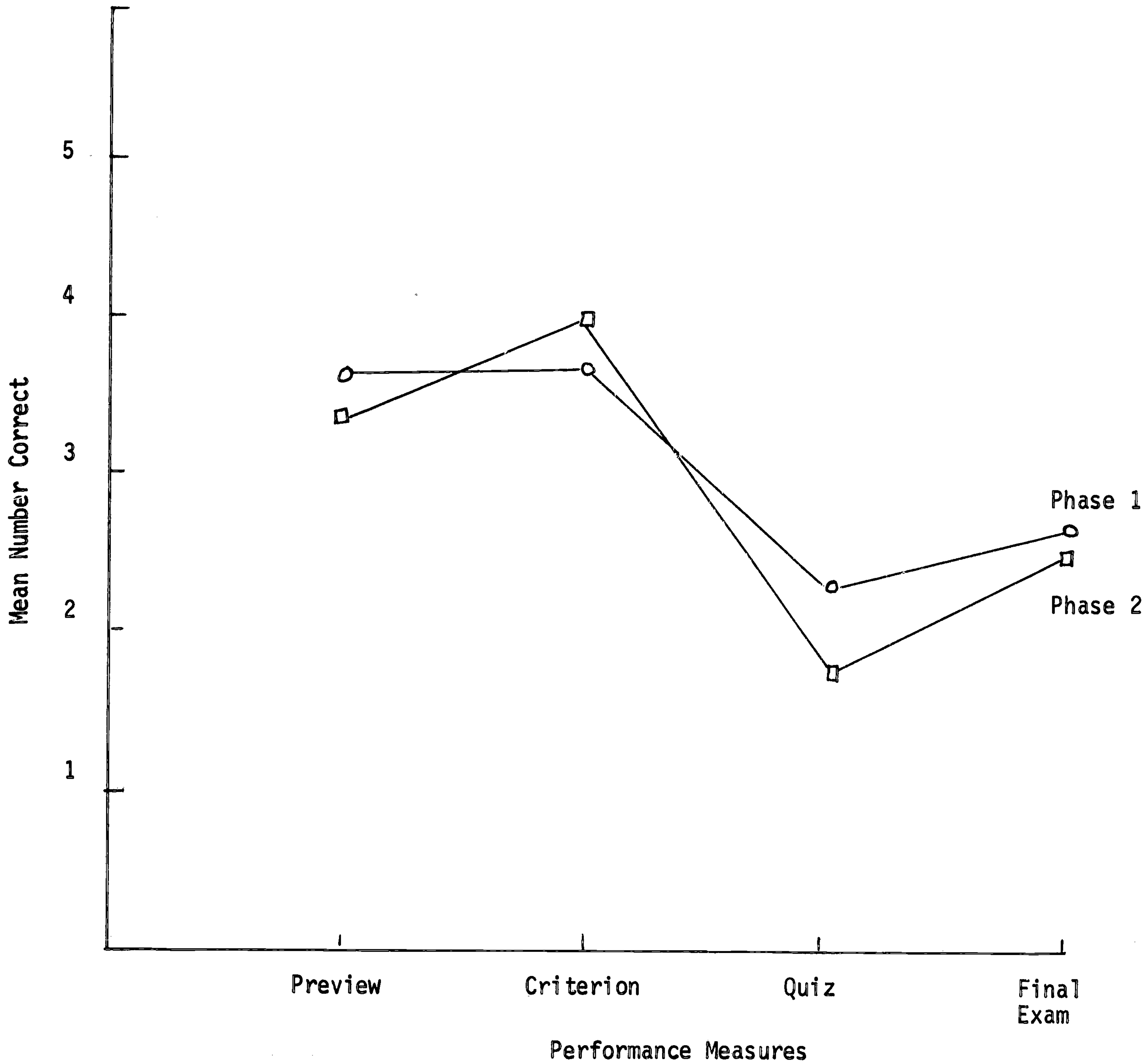


Figure 4--Mean Number Correct on Unit II Preview, Criterion, Quiz, and Final Examination Questions

2. LATENCY

Figures 5 and 6 present the mean latency in seconds on the preview, criterion and quiz questions for Unit I and Unit II respectively. The time taken on the preview and quiz questions in Unit I for the two groups was fairly similar. The larger difference in time taken between the two groups on the criterion questions may be a reflection of the difference in performance on this measure as was shown in figure 3. That is, the increased time taken by the adaptive model group (Phase 2) on the criterion questions in Unit I may be a reflection of the increased difficulty of these items as shown in figure 3. As indicated in figure 6, the latency measures in Unit II for the two groups are almost overlapping. The great increase in time taken on the quiz questions for both groups as compared with the criterion questions parallels the finding of low quiz performance as compared with criterion performance shown in figure 4. This increased time taken on the quiz in Unit II would seem to indicate that the questions were difficult and further that the trainees were attempting to answer the question rather than merely guessing.

3. CONFIDENCE

Figures 7 and 8 present the mean confidence of the trainees in their responses on the preview, criterion, and quiz questions for Unit I and Unit II respectively. It should be noted in figure 7 that confidence for both groups in Unit I was low on the preview questions, as would be expected. Confidence increased after instruction (i.e., on the criterion questions), and was maintained on the quiz. The confidence is parallel across the three measures for the two groups. The confidence on Unit II as seen in figure 8 is again relatively parallel for the two groups. On Unit II however, confidence is rather high on the preview measures, increases only slightly after instruction, and then drops on the quiz questions. This would appear to indicate that the quiz items were not measuring the same thing as were the preview and criterion questions (i.e., they were not parallel) as was indicated by the performance measures on this unit.

4. ATTITUDES

A sum score on the attitude questionnaire for each subject was obtained by scoring a 1 for strongly disagree to a 5 for strongly agree on each positive item and the reverse for negative items. The means and standard deviations for each group are given in table 8.

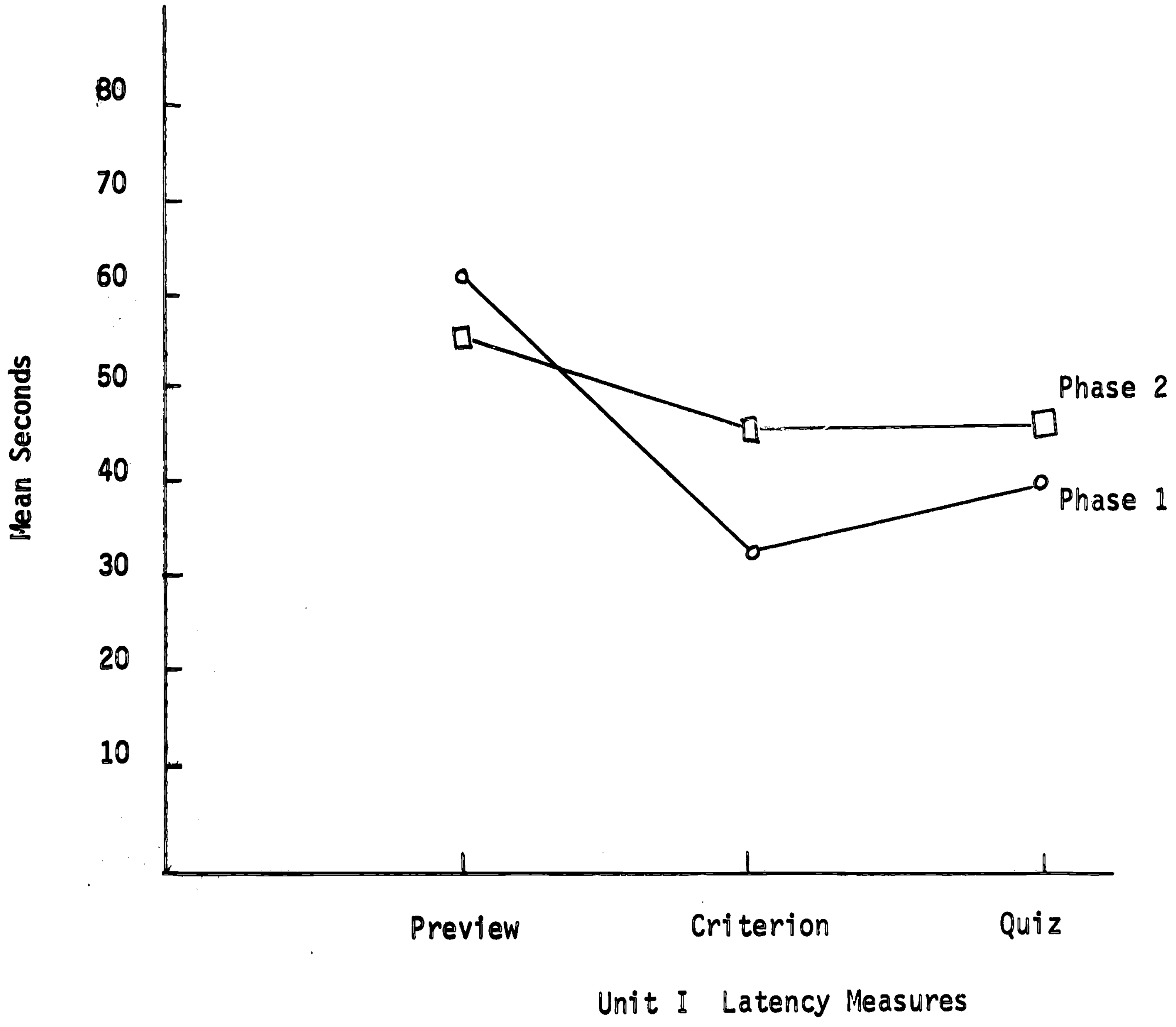


Figure 5--Mean Seconds on Unit I
Preview, Criterion, and Quiz Questions

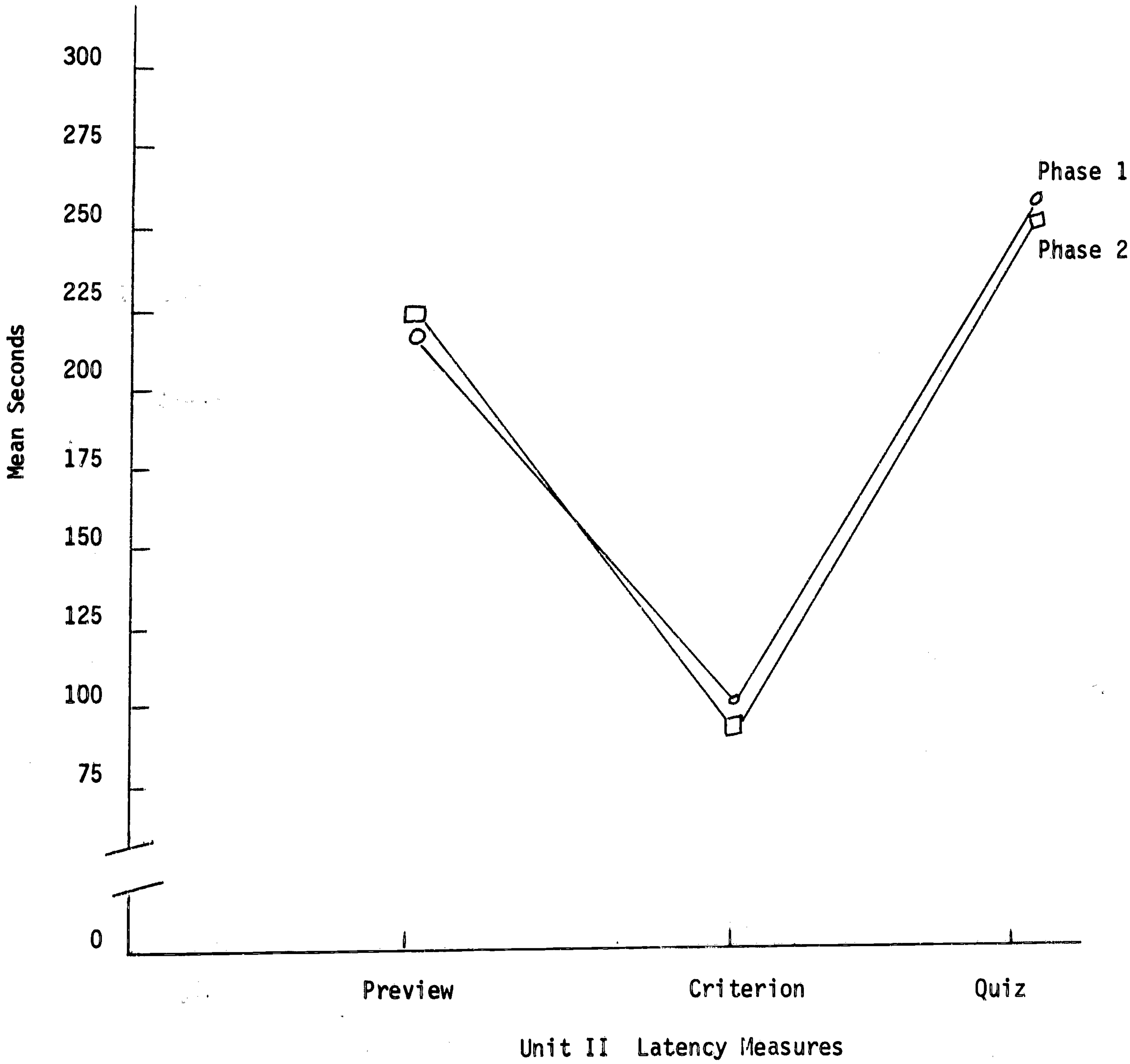
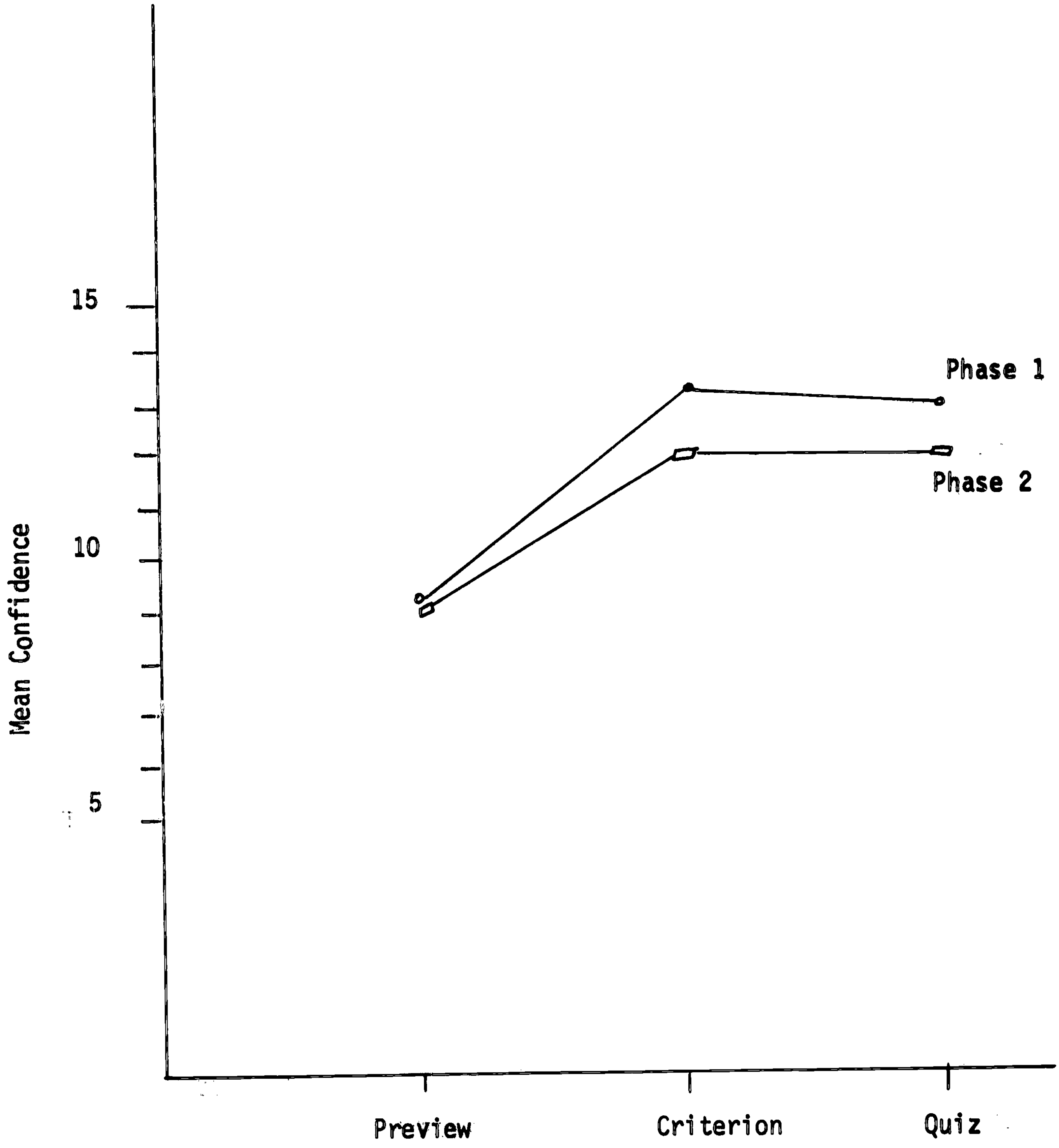


Figure 6--Mean Seconds on Unit II Preview, Criterion, and Quiz Questions



UNIT I CONFIDENCE MEASURES

Figure 7--Mean Confidence on Unit I
Preview, Criterion and Quiz Questions

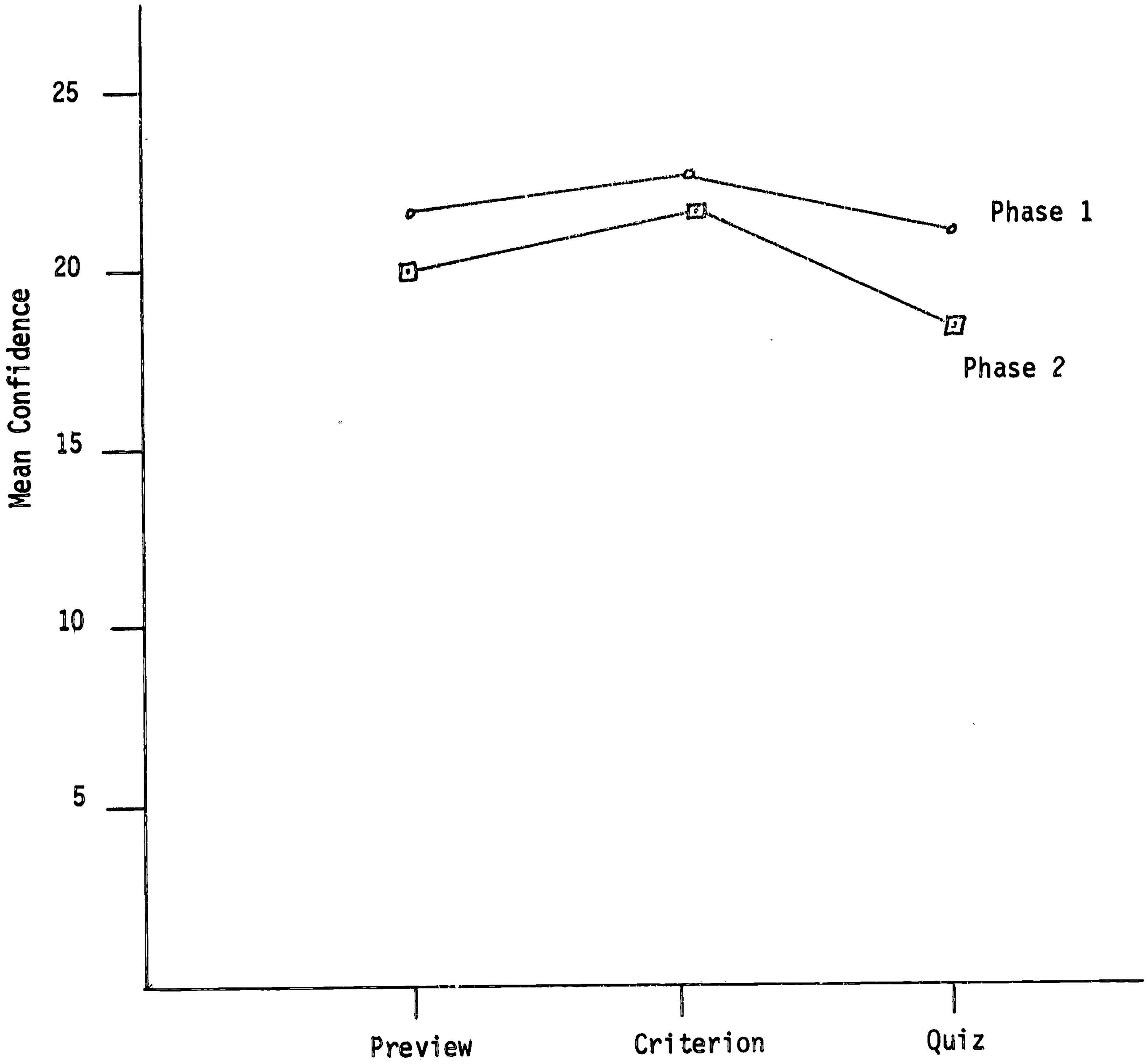


Figure 8--Mean Confidence on Unit II
Preview, Criterion and Quiz Questions

TABLE 8

MEAN ATTITUDE SCORE FOR PHASE 1 AND PHASE 2 TRAINEES

	MEANS	STANDARD DEVIATION
Phase 1	50.45	4.51
Phase 2	49.09	6.04

A t-test for significance of the difference between the means yielded a t of .62 which, with 20 degrees of freedom, is not significant at the .05 level.

SECTION V

DISCUSSION

A. REVIEW OF THE RESULTS

The results on Unit I of the training materials present a generally favorable picture for the adaptive model group. The pre-quiz decision model directed three of the eleven trainees to remedial instruction. Of these three, one was also directed to remediation after the quiz. A total of five trainees received remediation after the quiz (see table 7). The performance measures indicated that although the adaptive model group had a lower entry level of behavior and gained slightly less during instruction, they achieved about the same level of performance as the control group (Phase 1) on the quiz and final examination for the unit (see figure 3). It should be pointed out that the decision criterion for branching a trainee to remediation was that his predicted performance had to be equal to or greater than the mean of the control group. In this sense then, the adaptive decision model was effective. Had a more stringent criterion level been used, the overall performance of the adaptive model group might have been raised even higher. However, since performance on the quiz was at the 50 percent level and performance on the final examination was only slightly higher, it might also be posited that if the remedial instruction had been more extensive, the adaptive model group would have performed even better on the quiz and final examination. The relative effect of the criterion level and the extensiveness of the remediation is difficult to assess given the relatively small number of subjects in this investigation. It had been anticipated that 20 or more trainees could be obtained for the Phase 1 study; however, when the time came for the study to be conducted many of the Naval Reservists had conflicting duties.

The data on Unit II, on the other hand, did not show such a favorable trend for the adaptive model group. This finding appears to be more a function of the design of the training materials than of the adaptive model. The performance, latency, and confidence measures in Unit II (see figures 4, 6, and 8) for the adaptive model group and the control group are almost overlapping. The extreme drop in performance on the quiz and final examination in Unit II for both groups (as shown in figure 4) indicated that the quiz and final examination questions were not comparable with the preview and criterion items. Indeed, they appear to be more difficult. If it had just been the case that the training materials were poorly designed, such an extensive drop should not have occurred. Nine of the eleven trainees had been directed to the Unit II pre-quiz remediation, but this additional instruction did not seem to help them on the quiz. The trainees in both groups took more than twice the amount of time to answer the quiz questions than they did on the criterion questions (see figure 6). Six of the nine trainees who received the pre-quiz remediation should have received the post-quiz remediation but did not due to a coding error in the computer language.

It is difficult to assess the effect of this error particularly in light of the apparent difference in difficulty of the quiz and final examination questions as compared with the criterion questions. It is interesting to note that the six trainees who missed this instruction had a mean score of 1.83 on the five final examination questions covering that unit, whereas the remaining five trainees who did not need this instruction had a mean score of 3.20 on the five final examination questions covering Unit II.

The lack of parallel development of the quiz and final examination questions with the preview and criterion questions in Unit II is also implied in the findings on the confidence measures (see figure 8). Confidence is rather high on the preview questions and increases slightly on the criterion questions. However, the trainees confidence on the quiz drops below that on the preview items. This was not the case for Unit I (see figure 7). Confidence was low on the preview, increased on the criterion questions, and was maintained at about the same high level on the quiz for both groups.

B. METHODOLOGICAL CONSIDERATIONS

Several methodological procedures employed in this investigation that might have hindered the demonstration of the true extent of the effectiveness of the adaptive procedures employed should be mentioned. The first of these relates to the preview items. These items were spaced throughout the instruction so that if performance on these measures did relate to final performance, a trainee might be branched ahead to the next concept if he answered that preview question correctly. These measures did not show any significant relationship with final performance, and they were not used in the model building. It did appear in Unit I that the adaptive model group did have less prior knowledge. However, since the preview questions were spaced out over the instruction, and since the training materials did appear to be heirarchical in nature, it would have been difficult to determine the groups' true entry level to effectively show relative gains. Perhaps a complete pretest should have been given before any training started.

Another hinderance relates to the nature of the evaluation items. It should be recalled that one question was used to assess mastery of a concept, and a parallel question was developed for the end-of-unit quiz in addition to one for the final examination. A salient question in educational research is what are the appropriate criteria for determining whether a learner has mastered a given concept. Is one question enough? Are two questions better than one, or three better than two? As indicated in table 5, the quiz and final examination reliabilities for the Phase 1 data were not extremely high. This would indicate that the criteria for assessing mastery were not as effective as they should have been. Considering the degree of difficulty of the Unit II instructional materials, one question per concept on the criterion, quiz, and final examination measures may not have given an effective measure of mastery of the concept.

A further consideration relates to the variables that were identified to be measured during the learning process for possible inclusion in the adaptive model. Performance and latency were measured on preview, acquisition, criterion and quiz frames. Confidence was assessed on preview, criterion and quiz questions. Table 4 presented the variables that were selected for inclusion in the regression equations based on the Phase 1 data. Considering the discussions relating to the difficulty of the material, the nature of the evaluation items, and the sample size, the question arises as to whether the variables identified were the most effective ones and whether other variables might have been selected. Those variables that involved the largest number of observations, i.e., acquisition performance and latency, seemed more reliable. The relationships of the confidence measures to the other indices were somewhat unstable. The difficulty of the materials may well have contributed to these unstable relationships. However, a more effective assessment of a trainee's confidence might have been to simply ask him if he felt ready to proceed to the next concept.

The final consideration relates to the procedure of telling the trainee that he was receiving remedial instruction and why. The rationale was that if the trainee knew why he was performing below average, he would be able to effectively improve his performance. However, this might have had a deleterious effect in terms of reducing the trainee's motivation, particularly if he felt that the instruction was difficult and irrelevant.

SECTION VI

CONCLUSION

A methodology for producing a model for adaptive training via computer-assisted instruction utilizing regression analysis techniques was developed. The model was shown to be effective in identifying those trainees who needed remedial instruction. The results showed that although the adaptive model group started with less prior knowledge and performed at a lower level throughout the mainline of training, they performed comparably on the final examination as compared with a group that studied what was essentially a linear program. This result was only seen on the first half of the training materials. Certain methodological considerations such as the difficulty of the material, the nature of the remedial instruction, the development and number of the evaluation items and a coding error in the computer programming language were discussed as possible inhibiting factors in demonstrating the true effectiveness of the adaptive model on the second half of the training materials.

SECTION VII

RECOMMENDATIONS

The implications for future research in the development and utilization of adaptive models in computer-assisted instruction are these:

1. Regression analysis techniques can be utilized to identify those variables that relate to final performance and to establish the decision logic to be employed in the development of adaptive training models. These techniques could have high payoffs where the training system allows for real-time analysis of each individual's performance.

2. In developing the adaptive training models the instructional materials should be difficult enough so that some variance in performance is allowed to exist in order to establish relationships among the variables, but not so difficult as to create an excessive amount of variance.

3. Further research needs to be conducted to establish the appropriate criteria for determining whether a learner has mastered a given concept and to establish the appropriate type and amounts of instruction to be presented after determination of a learner's lack of mastery.

4. Further investigations should be conducted to identify other variables that might be effectively utilized in adaptive training models.

In this investigation a large step program with remedial instruction was used. Consideration should be given to the use of other program designs such as a small step program with a decision logic employed to branch trainees ahead if they are performing satisfactorily. In addition, adaptive training models might well be utilized in Computer-Managed Instruction where the majority of the trainee's time on the computer is devoted to evaluation of performance, and the bulk of instruction presented "off-line."

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APPENDIX A

INSTRUCTIONAL MATERIALS

After all revisions, additions, and deletions the final Boolean algebra program included two Units and eight concepts as shown below. The number of information and question frames is given by concept and unit.

Unit I

(Concept units)	INFORMATION FRAMES	QUESTION FRAMES
1. Elements in mathematical logic	8	3
2. Elements in set theory	8	3
3. Elements in switching networks	9	4
TOTAL FRAMES	25	10

Unit II

(Concept units)	INFORMATION FRAMES	QUESTION FRAMES
4. AND operation in logic	6	2
5. AND operation in set theory	6	12
6. AND operation in switching networks	4	6
7. OR operation in logic	5	3
8. OR operation in set theory	6	13
TOTAL FRAMES	27	36

APPENDIX B

CONFIDENCE RATING SCALE

1 I GUESSED AT THE ANSWER.

2 I KNEW A LITTLE ABOUT THE QUESTION, BUT MY ANSWER IS PROBABLY WRONG.

3 I AM HALF SURE MY ANSWER IS CORRECT.

4 I AM PRETTY SURE MY ANSWER IS CORRECT.

5 I AM SURE MY ANSWER IS CORRECT.

APPENDIX C

ATTITUDE QUESTIONNAIRE

(NOTE: The Phase 1 summary data are given above the scale for each of the questions and the Phase 2 summary data are given below the scale for each of the questions.)

This is not a test of information, therefore, there is no one "right" answer to a question. Your opinions will be strictly confidential. You do not need to put your name on this questionnaire. Please be frank and honest in your replies.

Thank you!

1. As a change of pace from usual training activities, Computer-Assisted Instruction was welcome.

			7	4
:	:	:	:	:
Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
	1	1	7	2

2. I would like to have more of my Naval Reserve training by Computer-Assisted Instruction.

		1	7	3
:	:	:	:	:
Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
	1	3	5	2

3. I enjoyed working at my own pace through the materials.

			5	6
:	:	:	:	:
Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
			5	6

4. I felt as if I had a private tutor while on Computer-Assisted Instruction.

	2	1	5	3
Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
	1	3	3	4

5. While taking Computer-Assisted Instruction I felt challenged to do my best work.

	1	2	6	2
Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
		2	5	4

6. I was encouraged by the computer's immediate response to my questions.

		1	6	4
Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
		2	5	4

(NEGATIVE ITEM)
7. The Computer-Assisted Instruction situation made me feel quite tense.

	7	1	3	
Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
1	4	1	1	3

(NEGATIVE ITEM)
8. I found myself just trying to get through the material rather than trying to learn.

1	7	2	1	
Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
3	3	3	2	

(NEGATIVE ITEM)

9. I felt that the course was somewhat difficult.

Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
	4	3	4	
	6	1	4	

(NEGATIVE ITEM)

10. I was given answers but I still did not understand the questions.

Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
1	6	2	2	
1	5	4	1	

11. In view of the effort I put into it, I was satisfied with what I learned while taking Computer-Assisted Instruction.

Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
		1	9	1
		2	6	3

(NEGATIVE ITEM)

12. While taking Computer-Assisted Instruction I felt isolated and alone.

Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
1	9		1	
2	3	2	3	1

13. The computer could be widely used in my Naval Reserve training.

Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
		2	4	5
		2	8	1

14. In your opinion, what was the <u>most desirable</u> feature of the Computer-Assisted presentation?

Phase 1--ability to proceed at own pace (8); wrong answers were explained (2); immediate feedback (1)

Phase 2--can proceed at own pace (5); immediate feedback (4); review of material (1); it didn't outrank me (1)

15. In your opinion, what was the most undesirable feature of the Computer-Assisted presentation?

Phase 1--no review allowed (3); brightness and jumping of figures (3). Phase 2--impersonal (1); too quick reaction (1); fuzzing and jumping diagrams (2); tendency to guess at materials you don't understand or like (1).

16. If you have any other comments please make them in the space below.

APPENDIX D

TRAINEES' COMMENT SHEET

Please indicate below whether you received any of the reviews before and/or after either quiz. Also indicate your opinion of the statements you received before each review and whether you felt that the reviews were helpful.

Did you receive the review before quiz 1 ______? What was your reaction to the statement you received before the review? ____ Did you feel that the review was effective? ______ If not, why not? ____

Did you receive the review after quiz 1 ______? What was your reaction to the statement you received before the review? ____ Did you feel that the review was effective? ______ If not, why not? ____

Did you receive the review before quiz 2 ______? What was your reaction to the statement you received before the review? ____ Did you feel that the review was effective? ______ If not, why not? ____

Did you receive the review after quiz 2 ______? What was your reaction to the statement you received before the review? ____ Did you feel that the review was effective? ______ If not, why not? ____

APPENDIX E

STEPWISE REGRESSION EQUATION CALCULATIONS FOR EACH OF THE FOUR INTERVENTION POINTS

UNIT 1 PRE-QUIZ

Step 1

Percent Performance = x_1 Multiple R = .5677, R^2 = .3223

$\hat{y} = .03958\ (x_1) - 1.60417$

Step 2

Percent Performance = x_1 Learning Latency = x_2

Multiple R = .6068, R^2 = .3682 $.10 < p < .25$

$\hat{y} = .3397\ (x_1) + .00158\ (x_2) - 2.39090$

UNIT 1 POST-QUIZ

Step 1

Quiz Performance = x_1 Multiple R = .4929, R^2 = .2429

$\hat{y} = .49286\ (x_1) + 1.82857$

Step 2

Quiz Performance = x_1 Quiz Confidence = x_2

Multiple R = .6506, R^2 = .4233 $.10 < p < .25$

$\hat{y} = .43487\ (x_1) + 1.8878\ (x_2) - .50693$

UNIT 2 PRE-QUIZ

Step 1

Percent Performance = x_1 Multiple R = 3.712, R^2 = .1378

$\hat{y} = .03386\ (x_1) - .40042$

Step 2

Percent Performance = x_1 Criterion Latency = x_2

Multiple R = .5551, R^2 = .3081

$\hat{y} = .03870\ (x_1) + .01573\ (x_2) - 2.44452$

Step 3

Percent Performance = x_1 Criterion Latency = x_2

Learning Latency = x_3

Multiple R = .7674, R^2 = .5889 $.05 < p < .10$

$\hat{y} = .09705\ (x_1) + .05823\ (x_2) - .00682\ (x_3) - 2.80892$

UNIT 2 POST-QUIZ

Step 1

Quiz Performance = x_1

Multiple R = .5637, R^2 = .3178 $.05 < p < .10$

$\hat{y} = .5673\ (x_1) + 1.30392$

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